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FURTHER STUDIES ON FLAG SMUT OF WHEAT

W. H. TISDALE, *Pathologist in Charge of Cereal Smut Investigations*, and C. E. LEIGHTY, *Agronomist in Charge of Eastern Wheat Investigations, Office of Cereal Crops and Diseases, Bureau of Plant Industry*, and BENJAMIN KOEHLER, *Associate Chief in Crop Pathology, Illinois Agricultural Experiment Station*

CONTENTS

INTRODUCTION

Flag smut (*Urocystis tritici* Kcke.), known for many years to be a destructive disease of wheat in Australia and recently found to cause heavy losses in China, probably was first discovered in the United States in May, 1918, in St. Louis County, Mo. (*4*).[1] This discovery, however, was not reported for several years. In May, 1919, the disease was found in Madison County, Ill. Immediately after the discovery in Illinois, arrangements were made for a cooperative investigation of the disease by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Agricultural Experiment Station of the University of Illinois. A study was made of the history of the occurrence of flag smut, the losses caused, the symptoms of the disease,

[1] Italic numbers in parentheses refer to "Literature cited," p. 11.

NOTE.—The writers are indebted to Miss M. A. Griffiths, assistant pathologist, cereal smut investigations; S. S. Carney, county agricultural agent, Rock Island County, Ill.; G. H. Dungan, assistant chief in crop production, Illinois Agricultural Experiment Station; A. G. Johnson, senior pathologist in charge of cereal disease investigations; and E. R. Ranker, associate physiologist in corn smut investigations, for assistance in the experiments.

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against flag smut in the infested area in Illinois must aim at keeping susceptible wheats off the land for at least two years following a smutted crop.

SEED TREATMENT

In the present investigations the tests in treating seed with disinfectants were conducted only one year. Only dusts were used, and the results confirm those previously reported (*5*), in that seed disinfectants destroyed flag-smut spores carried on the seed. In the previous experiments it was shown that disinfectants did not furnish full protection against soil-borne spores. Of the seven dusts used in this experiment, all except one (Du Pont C–10–G) controlled flag smut satisfactorily. The dusts which controlled the disease were copper carbonate, Du Pont S. D. No. 3, Du Pont S. D. No. 4, Du Pont S. D. No. 7, Du Pont C–20–G, and Corona No. 40–S. Artificially smutted seed of Harvest Queen wheat was used for this experiment. In the check rows, sown with artificially inoculated seed not treated with disinfectant, only 7. 6 per cent of flag smut occurred.

VARIETAL RESISTANCE

The wheat varieties which showed a high degree of resistance in the previous investigations (*5*, *6*) were given further test in these experiments. In addition numerous commercial wheats from various parts of the country were tested, in order to obtain information on their reaction to flag-smut infection in anticipation of the possible spread of the disease. Many of these wheats, of course, are not adapted to conditions existing where the experiments were conducted, but it was hoped that valuable information might be obtained. A few spring wheats were fall sown, but all of these were winterkilled. No spring sowings were made for two chief reasons: (1) Spring wheats are not grown successfully at Granite City, Ill., where the experiments were conducted; (2) in previous experiments (*5*), inoculated seed sown in the spring produced only smut-free plants, which showed that very late fall sowing (November 23–30) and spring sowing (April 4) were unfavorable for flag-smut infection, owing to the low soil temperatures.

The seeds were inoculated in the same way as in the previous experiments (*5*), that is, by shaking them in a closed envelope or other closed container with a sufficient quantity of flag-smut spores to make the seed appear dark in color. The spore material was obtained by crushing or grinding the dried smutted plants in a food chopper and rubbing the spores through a fine sieve. The same strain of Harvest Queen (Red Cross) wheat used for a control in previous experiments was employed. After being inoculated the seed was sown in rod rows 1 foot apart. Dates of sowing ranged from September 24 to October 4. Early sowing is more conducive to injury by the Hessian fly and favors flag-smut infection because of the warmer soil temperatures.

Very little wheat in the experimental plots survived the winter of 1923–24, and consequently no results were obtained. The plants which survived were smut free almost without exception. During

the course of the experiments some of the varieties were discontinued because of winterkilling, and others were dropped as soon as they proved to be susceptible. The results of these varietal tests are given in Table 1.

TABLE 1.—*Reaction of varieties and strains of hard red and soft red winter, white, and club wheats to infection by flag smut when grown from artificially inoculated seed, at Granite City, Ill., in 1923, 1925, and 1926*

Variety or selection	C. I. No.	Source of seed [1]	Percentage of infected plants		
			1923	1925	1926
Hard red winter wheats:					
Beloglina		Illinois	0	Trace.	
Blackhull	6251	Kansas	0	0	0
Do		do		0	
Hussar	4843	Virginia	0	0	0
Iobred	6934	Iowa		Trace.	
Iobred (selection)	6934	do		Trace.	
Kanmarq	6937	Kansas		0	
Kanred—					
Kanred		Illinois	0	0	
Do		Kansas	.4	0	0
Do	5146	do	0		
Do	6994	Wisconsin	0		
P. 1066	5879	Kansas	.4	0	0
P. 1068	5880	do	1.9	0	0
Kharkof—					
Awned selection		Illinois	0		
Awnless selection		do	12.8		
Michikoff	6990	Indiana	3.2	0	2.1
Minard	6690	Minnesota		0	0
Nebraska Hybrid No. 28	5147	Kansas	0	0	
Padui	6153	Minnesota		1.0	
Pesterboden—					
Budapest	5789	Wisconsin	4.2	0	
Hungarian		Illinois	1.7		
Sherman	4430	Oregon		0	0
Tenmarq	6936	Kansas		0	0
Turkey—					
Ired (Ill. 10-110)		Illinois	0	0	0
Malakof		do	.6		
Do	6988	Indiana	.1	0	0
Turkey Hybrid No. 509		Illinois	2.3		
Turkey Hybrid No. 402		do	3.5		
Turkey Hybrid No. 531		do	.1	Trace.	
Turkey Hybrid No. 532		do	.8		
Turkey	6982	Indiana	.3	0	0
Do	6996	Wisconsin	2.4		
Do	7005	Illinois		0	0
World's Champion		do	.4	0	0
Soft red winter wheats:					
Ashland	6986	Kentucky	.8	0	.2
Berkeley Rock	6941	Michigan	0	0	.4
China	6965	Pennsylvania	0	0	0
Currell	6952	Kentucky	0	0	.5
Flint—					
Little Red		Virginia	13.8	Trace.	
Forward—					
Forward (selection)		New York		0	
Forward	6691	do	0	0	0
Fulcaster—					
Bearded Purplestraw	1911	Virginia	1.0	0	
Dietz		Missouri	6.5		
Do	3387	Virginia	[2] 3.9	0	.1
Do	1981	do	2.0		
Egyptian	6945	Michigan	0	0	0
Eversole	3011	Virginia	.2	0	0

[1] In most cases seed was supplied by the agricultural experiment stations of the States named. All but three of the lots from Virginia (Little Red, Fulcaster 6973, and Stoner) were from the Arlington Experiment Farm of the United States Department of Agriculture at Rosslyn, Va., near Washington, D. C.

[2] This percentage probably is too high, as mixtures of smutted off-type plants were found in the row on second inspection.

TABLE 1.—*Reaction of varieties and strains of hard red and soft red winter, white, and club wheats to infection by flag smut when grown from artificially inoculated seed, at Granite City, Ill., in 1923, 1925, and 1926*—Continued

Variety or selection	C. I. No.	Source of seed	Percentage of infected plants		
			1923	1925	1926
Soft red winter wheats—Continued.					
Fulcaster—Continued.					
Fulcaster	3407	Virginia	0	0	0
Do	6953	Kentucky	0	0	0
Do	6977	North Carolina	0	Trace.	
Do	6973	Virginia		0	
Do	6974	Illinois		0	0
Do	6162	Virginia	Trace.		
Do		Missouri	.7		
Do			Trace.		
Lancaster	1945	Virginia	.7	0	0
Do	6948	Michigan	0	0	
Marvelous		Indiana	.4		
Stoner (Miracle)	6964	Pennsylvania	0	0	
Stoner	2980	Virginia	.5	0	
Do	6957	North Carolina	0	0	0
Do		Virginia	0	0	
Fulhio	6970	Ohio		0	0
Do	6999	do		0	
Fultz:					
Bluestem Fultz		Kentucky	.4		
Fultz	6954	do	1.4	Trace.	
Fultz (certified)		Illinois	1.1	2.2	
Georgia Red	6955	Georgia	0	14.7	
Gipsy—					
Gipsy	5579	Virginia	.9	0	0
Do	3440	do	.3	0	0
Reliable	3508	do	.2	0	0
Gleason	6956	North Carolina	0	0	
Do	6978	do		Trace.	
Gladden—					
Gladden (selection)		Ohio		Trace.	
Gladden	7000	do		Trace.	
Do	6959	do	0	Trace.	
Goens—					
Goens	6946	Michigan	1.7	Trace.	
Red Chaff	6992	Indiana	1.1	0	.6
Grandprize—					
St. Louis Grandprize	5627	do	.3	0	.2
St. Louis Grandprize (selection)	5627	do		Trace.	
Harvest Queen selection			8.2		
Illini Chief	6947	Michigan	0	Trace.	
Imperial Amber	3447	Virginia	.9	Trace.	
Leap—					
Leap Prolific	6966	Pennsylvania	[3]	0	
Do	6958	North Carolina	[3]	0	
Do	6979	do		0	
Mammoth Red	2008	Virginia	0	0	0
Mediterranean—					
Mediterranean	3467	do	Trace.	Trace.	
Do	1395	do	.2	0	0
Mediterranean (selection)	6968	Texas		0	0
Do		Missouri	.6		
Miller's Pride	4865	Virginia	.3	0	0
Miller's Pride (selection)		do	0		
Missouri Bluestem	1912–2	do	.1	0	
Nigger	5689	Pennsylvania	0	0	
Ohio (9920)	7002	Ohio		0	0
Ohio (16983)	7004	do		0	.1
Ohio (14818)	7003	do		0	.2
Penquite—					
Velvet Chaff (selection)		Virginia	0	0	
Velvet Chaff	3068	do	0	0	0
Pennsylvania No. 44	6962	Pennsylvania	0	0	.1
Poole—					
Harvest King	6963	do	1.0	0	1.0
Poole	1979	Virginia	.3	0	0
Do		Tennessee	14.1		
Do	3489	Virginia	2.1		
Do	6991	Indiana	.5	0	.2
Portage	6960	Ohio	0	0	0
Purplestraw—					
Alabama Bluestem	6976	North Carolina		2.3	

[3] No plants.

TABLE 1.—*Reaction of varieties and strains of hard red and soft red winter, white, and club wheats to infection by flag smut when grown from artificially inoculated seed, at Granite City, Ill., in 1923, 1925, and 1926*—Continued

Variety or selection	C. I. No.	Source of seed	Percentage of infected plants		
			1923	1925	1926
Soft red winter wheats—Continued.					
Red May—					
Beechwood		Missouri	[2] 4.0	0	
Early Harvest	4852	Virginia	[2] 0.3	0	0
Michigan Amber		Indiana	3.3	Trace.	
Do	6985	Michigan	.6	Trace.	.1
Do	6989	Indiana	1.2	0	
Michigan Wonder	5589	Virginia	1.7	Trace.	0
Do	6949	Michigan	1.3		
Orange	4868	Virginia	6.1		
Red Republic		Missouri	1.2	0	
Red Rock	5597	Virginia	0	0	
Do	6951	Michigan	0	0	0
Do	5976	Virginia	1.5		
Red Russian	3497	do	0		
Do	6995	Wisconsin	0		
Red Wave		Indiana	.5		
Do	6967	Pennsylvania	.9	0	
Rudy	6993	do	0	0	0
Rudy (selection)		do		Trace.	
Rural New Yorker No. 6	3515	Virginia	Trace.	0	
Shepherd	6163	do	Trace.	0	0
Shepherd's Perfection	6984	Michigan	1.0	0	0
Triplet	5408	Washington	0	0	
Trumbull	6961	Ohio	0	0	
Do	6981	Indiana	0	0	
Do	7001	Ohio		0	.2
Trumbull (selection)		do		0	
Do		do		0	
Ulta No. 834	5747	Virginia	0		0
Valley	5658	do	1.2		
White wheats:				Trace.	
American Banner	6943	Michigan	1.9		
Arcadian—				0	
Early Arcadian	3390	Virginia	.6		.3
Baart	1697	Oregon	[3]		.3
Dawson—					
Honor	6161	New York	4.2		
Federation	4734	Oregon	[3]		
Gold Coin—				0	
Junior No. 6	6971	New York	0	0	
New York No. 6	6950	Michigan	0		
Hard Federation	4733	Oregon	[3]		
Do	4743	do	[3]	0	
Kofod		Utah		0	
Martin	4463	Oregon	0	1.3	
O. A. C. No. 104	6983	Ontario	6.3		
Pacific Bluestem	4067	Oregon	[3]	Trace.	
White Odessa	4655	do			
Windsor—				Trace.	
Early Windsor	6944	Michigan	2.0		
Do	4159	Georgia	0		
Club wheats:					
Hybrid 123	4511	Oregon	[3]		

[2] This percentage probably is too high, as mixtures of smutted off-type plants were found in the row on second inspection.
[3] No plants.

In order to show the significance of the percentages of infected plants, Harvest Queen used as a check was replicated 18 times in 1923 at intervals throughout the plot. The percentages of plants showing flag smut in these replications ranged from 9 to 49.7 with an average of 23.8. In the 9 replications of the Harvest Queen check in 1925, the percentages ranged from 4.4 to 12.5, with an average of 7.2. Much higher percentages occurred in some of the Harvest Queen selections, one having 61.2 per cent of smutted plants. In 1926 the highest percentage in the Harvest Queen check was 2.7, while certain

Harvest Queen selections produced as high as 20 per cent of smutted plants.

The data in Table 1 indicate that flag smut probably will never become as destructive in Illinois as it is in Australia and China, owing to the fact that many of the wheats grown in this country are highly resistant. Furthermore, it appears that climatic or other environmental conditions in the Illinois area are sometimes very unfavorable to the disease. Harvest Queen is the most susceptible variety that has been tested, but only 2 per cent of the plants of this variety were smutted in 1926, in contrast to 23.8 per cent in 1923. Following the severe winter of 1923–24, although from 3 to 40 per cent of the plants remained in the 54 rod rows sown with this variety, only five smutted culms were found in these rows. Unfavorable conditions of this kind may help to keep the disease in check over wide areas.

That conditions for flag-smut infection were much more favorable in 1923 than in 1925 and 1926 is shown also by the data in Table 1. Not only were the percentages of infection higher in susceptible varieties, but numerous varieties were slightly infected in 1923 that were free from smut in 1925 and 1926.

In many cases a trace or a low percentage of infection in one or more years is shown for varieties in Table 1. In some cases this is probably due to a slight admixture of susceptible varieties, or of susceptible strains within the variety, or even to occasional natural hybridization with a susceptible variety occurring in an otherwise immune sort. In field culture this mixture would be lost through natural selection where the disease is present in sufficient quantity, as badly diseased plants seldom produce seed.

Several of the varieties have been entirely free from smut throughout the experiments, and others have shown only a trace of infection. The names and complete records of these appear in Table 1 and in earlier publications (*5*, *6*) and need not be repeated here. Varieties well adapted to all districts where flag smut is now known in the United States are included among these immune or highly resistant sorts, and some of these are now being grown commercially in the flag-smut areas. Among the immune or highly resistant soft red wheats adapted generally to the flag-smut area are the following well-known varieties: China, Forward, Fulcaster (including Stoner), Fulhio, Gladden, Mammoth Red, Pennsylvania 44, Portage, Red Rock, Rudy, Shepherd, Penquite (Velvet Chaff), and others. These varieties and other selections not now of commercial importance could be used in the control of flag smut over most if not all of the area where soft red winter wheat is grown. It appears, therefore, that flag smut does not seriously menace the growers of soft red winter wheat.

Among the hard red winter varieties, Blackhull has been immune in tests covering three years, Hussar in tests covering four years, and Ilred (Ill. 10–110) in tests covering five years. One lot of Kanred from Illinois was immune for four years, but certain other lots of this variety occasionally have been slightly infected, and in one year seriously so. Malakof and Turkey are highly resistant. In general, it appears from these experiments that flag smut need not be feared in the area growing hard red winter wheat.

Of the white wheats, Gold Coin (Junior No. 6, or New York No. 6) and Martin have been immune in tests covering two years and Kofod in tests covering one year. Honor and O. A. C. No. 104 have shown considerable susceptibility. Several of the white wheats commonly grown in the Pacific Coast States have been sown in these experiments but have been winterkilled. The control of flag smut by means of resistant varieties appears practicable in sections to which Gold Coin and Martin are adapted, provided that change in environment does not cause change in the reaction toward the disease organism. The possibility of control on the Pacific coast by means of resistant varieties is still in doubt.

HEAD SELECTIONS

Harvest Queen wheat is well adapted to the districts where flag smut is prevalent in the United States, and it is now or has been one of the principal varieties grown in those districts. Unfortunately, however, it is very susceptible not only to flag smut but also to rosette, another disease that occurs in the flag-smut district in Madison County, Ill. A mass selection was made by McKinney (*3*) in 1919, in a field of Harvest Queen, of heads from plants that had developed normally in soil badly infested with rosette. This selection has remained free from the disease when grown in badly infested soil each year since the original selection was made. It is composed mainly of the Harvest Queen wheat but contains a slight admixture of other wheats.

Because of the good qualities of the Harvest Queen variety, such as high winter resistance and stiff straw, it seemed desirable to obtain a strain resistant to both rosette and flag smut. Consequently, head selections were made in the experimental plots of the resistant Harvest Queen at Granite City, Ill. The seeds of 127 of these heads were sown at Granite City in the fall of 1922; seeds of 250 of these heads were sown in 1923; and seeds of 100 of these heads were sown in 1924. In the sowings made in the fall of 1922 there were included also 14 selections of Harvest Queen from Grundy County, Ill., 17 head selections from two strains of Salzer's Red Cross obtained from La Crosse, Wis., and 32 head selections of Red Wave. In the sowings made in 1923, 227 head selections of several other varieties were included.

In all cases seed from the selected heads was inoculated with spores of flag smut and sown in separate head rows. All rows showing smut were discarded at harvest time the next year. The smut-free rows were harvested and used for further tests, unless discarded for other reasons. During the severe winter of 1923–24 many of the selections were killed, but all the plants that survived were smut free.

Of the 767 head selections tested, only 9 that have remained smut free have been retained. Four of these are selections made in 1922 and have been smut free for four years, namely, No. 22–9, a selection made in the rosette-resistant Harvest Queen but having a red chaff not typical of the variety, and Nos. 22–165, 22–185, and 22–187, selections of Salzer's Red Cross, likewise with a red chaff. The five smut-free strains among the selections made in 1924 (Nos.

24–6, 24–14, 24–18, 24–26, and 24–33) are all rosette-resistant Harvest Queen having the white chaff and other characters typical of this variety. These five selections have been tested for two years, in 1925 in single head rows and in 1926 in rod rows duplicated in different parts of the nursery. During this time they have produced no smutted plants. Tests in head rows frequently have proved to be inconclusive as an indication of resistance, on account of the small number of plants included. Rod-row tests are more reliable but are not fully conclusive. If these selections should maintain their resistance in further tests, they would have the qualities being sought in the Harvest Queen variety, namely, resistance to flag smut and rosette.

SUMMARY

Flag smut of wheat is known to occur in Australia, China, India, Japan, Spain, South Africa, and the United States. It was first discovered in the United States in St. Louis County, Mo., in 1918. It is now known to occur in several counties in Illinois and Missouri near St. Louis, and in a few counties in Kansas and Missouri in the vicinity of Kansas City.

Flag smut causes heavy losses in China and Australia, but it has not proved very destructive to wheat in the United States.

Spores of the causal organism, *Urocystis tritici*, have been found to live a full year in infested straw buried in the soil at Granite City, Ill., and then to cause infection of wheat.

Seed disinfectants, including copper carbonate and other dusts, prevent infection of wheat by flag-smut spores carried on the seed but do not control the disease satisfactorily if the soil is infested.

Many varieties of wheat that had proved highly resistant to flag smut in previous investigations have been studied further. In addition, numerous commercial wheats grown in different parts of the country were included in the experiments. Many of these wheats proved either highly resistant to or free from flag smut.

Among the immune or highly resistant soft red wheats adapted generally to the flag-smut area are the varieties China, Forward, Fulcaster (including Stoner), Fulhio, Gladden, Mammoth Red, Pennsylvania 44, Portage, Red Rock, Rudy, Shepherd, Penquite (Velvet Chaff).

Many head selections have been made from rosette-resistant Harvest Queen wheat and a few selections from other varieties, including Salzer's Red Cross and Red Wave. One red-chaffed selection made in a field of rosette-resistant Harvest Queen and three selections of Salzer's Red Cross made in 1922 have remained smut free during the four years they have been tested. Five rosette-resistant Harvest Queen selections made in 1924 have remained smut free for two years.

In tests made in the greenhouse at Arlington Experiment Farm during the winter of 1926–27, with artificially smutted seed, No. 22–185 produced 5.1 per cent smutted plants, No. 22–187 produced 21.1 per cent smutted plants, and No. 24–26 produced 9.1 smutted plants. Other selections did not produce smutted plants.

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